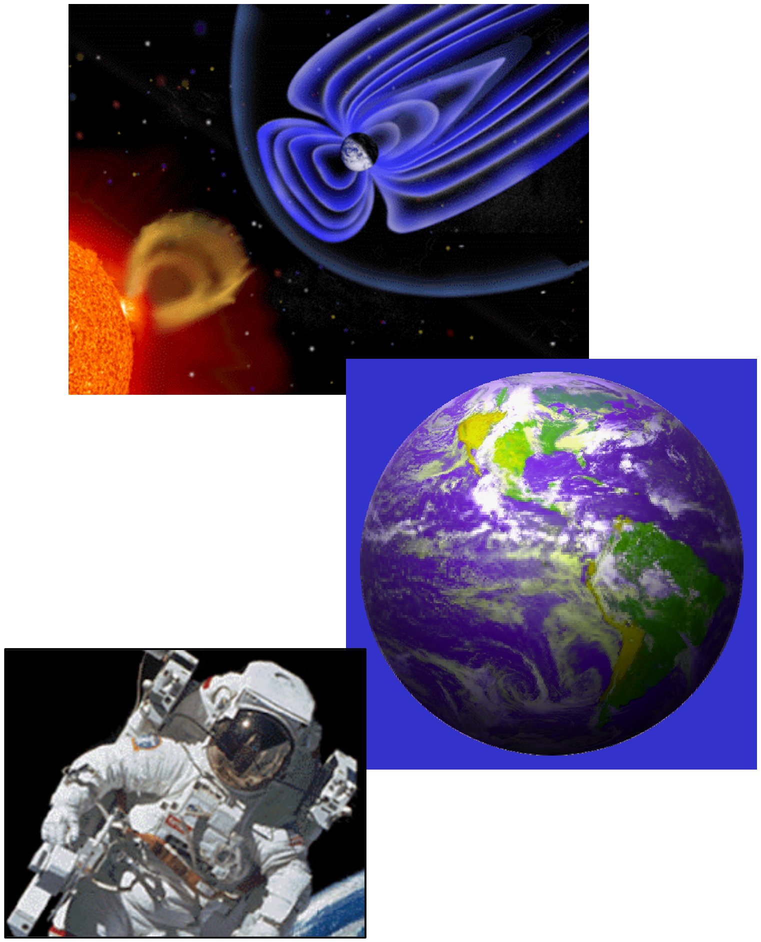

Section 6

Ground Segment

Background

NASA policy requires that the cost of developing a ground system and the cost of its operation during the life of a mission be included as part of the overall mission planning. In compliance with this policy and traditional engineering practice, the effect of orbit choice, instrument operation, and supporting spacecraft systems on the ground segment is being treated as an integral part of concept development for each of the LWS program core missions.

Life Cycle Methodology

Previous ground system concepts were based on using shared resources in a central facility, so that the cost of the required computing capability could be distributed among several different missions. From this central facility, data were distributed by magnetic tape or by electronic bulk transfer. The electronic bulk transfer required leased transmission lines of sufficient bandwidth to keep up with the mission data flow and provide the investigators with timely data.

This concept is not considered acceptable for the LWS core missions for several reasons:

- Different launch schedules, resulting in idle capability until later scheduled missions begin operations
- Significant up-front cost for facilities to accommodate all of the planned missions
- Plans for all the missions not developed in time to procure necessary operational ground systems
- Increased potential for costly changes resulting from incomplete requirements definition

Life Cycle Planning

Recent increases in workstation and microcomputer capabilities have resulted in low-cost, stand-alone systems that can perform mission operations and control functions. Operations and data processing capabilities can therefore be dedicated to a specific mission and located at any convenient site. Locating the operations and data processing capabilities at an investigator's facility reduces the communications link costs. If the receiving equipment, using a direct-to-ground capability, is located at the investigator's facility, communications link costs can be even further reduced or eliminated as follows:

- No underused or unused capabilities to be maintained while becoming obsolete
- For LWS core missions, no large up-front costs; facilities required for the LWS ground systems are only as large as the number of missions in operation and can be expanded or contracted as much and as often as necessary
- No limitation on the number of missions that can be handled at one time, because of central system limitations or because of a lack of physical space in the central facility to accommodate system operators and missions investigators
- Option to salvage or discard ground system components after mission operations are completed

Individual Mission Assessments

Computer and communications technology advances also provide considerable flexibility for the development of the LWS missions in considering what functions could best be performed on the spacecraft and what functions would best be performed on the ground. This offers the opportunity to develop flight and ground systems that optimize the cost of development, cost of operations, and ease of use.

It is essential to consider the actual requirements of the individual LWS missions in the development of the overall system. The total instrument requirements for each mission will be analyzed and a ground system designed to suit the instrument complement.

Considerations include:

- Type and volume of operational functions
- Frequency at which functions are performed
- Accuracy, precision, and resolution required

Mission Elements

Mission elements affecting the development and operation of the ground system are:

- **Orbit determination/navigation requirements:** the accuracy, precision, and resolution of the requirement, which in turn affects the type of sensors used, and the number of sensor samplings or ranging measurements to meet the requirements. For some of the LWS missions this will include stationkeeping.
- **Pointing requirements:** the field of view, accuracy, stability, and knowledge of the requirement, which in turn affects the type of sensors used and the number of sensor samplings needed to meet the requirement. It also includes any viewing constraints, such as the South Atlantic Anomaly (SAA) and any other fields or objects which could over-saturate and damage any of the instruments.
- **Data processing requirements:** the amount of data to be processed and, for initial processing, would include limits on the time latency that is acceptable, any quick-look data processing requirements, level of processing required, need for data sorting by time with overlap removal, and need for adding ancillary data to the experiment data.
- **Data and communications requirements:** the volume of data received can affect the location of ground system components such as uplink/downlink station, preliminary data processing facility, experimenters' facilities, and the processed data repository, since the volume of data will affect data transmission costs.

Mission Elements (cont.)

- **Telemetry bandwidth requirements**: There is significant competition for access to government allocations at S-band. X-band allocations are further limited to Earth exploration missions. The frequency authorizations recommended are government allocations at Ka-band. Usage of S-band is limited to low-bandwidth telemetry requirements and for command uplinks.
- **Type of operations:** based on whether the mission requires a significant amount of real-time interaction or is planned and the operations conducted according to a schedule.
  - Real-time operations involve significant interaction between mission investigators, the flight operations team, and the spacecraft. This type of operation benefits from the co-location of the science and flight operations teams, so that the science team can obtain a quick look at the data being received and then meet with the flight operations team to plan activities based on the data quick-look. This type of operation is also useful when there is minimal conflict among experimenters or where all experimenters have an interest in the same phenomenon.
  - For planned operations, the flight operations team can consult with the mission investigators and plan a schedule of activities. Commands to the satellite are stored online and sent to the satellite and executed according to the planned schedule. Co-location of the science and flight operations teams is not a significant benefit for this mode of operation. Two types of science operations have proven to add considerable cost to a mission and will be avoided as far as possible: Targets of Opportunity (TOOs) and Alternate Targets. Such operations require considerable planning, re-planning, scheduling, and re-scheduling efforts and often considerable software development effort.

LWS Core Missions

The four core missions of LWS fall into two categories — Solar missions and Plasma missions.

- **Solar missions (SDO and Sentinels):**
  - Instrument detectors pointed continuously at the Sun
  - Continuous large volume of real-time science data to be processed
  - Minimum slewing required

- **Plasma missions (RBM and IM):**
  - Wide variability in the types of orbits selected
  - Orbits largely determined by the location of the plasma field or fields being studied

Based on considerations discussed above, the SDO satellite will be in a geosynchronous orbit and the Sentinels mission will have multiple spacecraft in different heliocentric orbits. The orbits of the Sentinel satellite will significantly limit the amount of data that can be received.

The RBM mission will have multiple satellites in a fixed formation in highly elliptical orbits at low inclination, and the IM mission will have multiple satellites in fixed formations in both polar orbits and low-inclination orbits.

Effect of LWS Goals on Ground Operations

The goal of the LWS program, to develop the scientific understanding necessary to effectively address those aspects of the connected Sun-Earth system that affect life and society, has a significant effect on the development of ground operations for the identified core missions of the program. It primarily means that if the data collected is to be useful in predicting the effects of solar activity on life on Earth, the data latency must be kept to a minimum. Ideally the data should be made available to users in real time. The required orbits from which some of the data must be collected, however, preclude real-time availability for the users. Where real-time data availability is not possible, the latency must be kept to a minimum. This goal of minimum data latency has been considered in the recommended approaches for ground operations.

Ground Station Considerations

The wide variability in the orbits of the LWS missions will limit the use of ground facilities by more than one mission. The SDO in a low-inclination, geosynchronous orbit can be operated from a single ground station; however, the requirement for continuous downlink of high-rate solar data will preclude use of the ground station by any of the other LWS missions. The RBM mission requires highly-elliptical, low-inclination orbits of multiple satellites. It will require at least three ground stations, possibly with multiple antennas, at stations equally spaced around the Earth. The Sentinels mission will also require at least three ground stations, possibly with multiple antennas, equally spaced around the Earth. These stations may be required to receive data continuously from more than one Sentinels satellite at a time, resulting in a need for multiple antennas to both receive data from the Sentinels satellite and to track the highly-elliptical orbits of the RBM satellites. The IM mission will require two or three polar ground stations in order to minimize the data latency. Additionally, the IM mission will require at least one low-latitude station to receive data from the low-inclination satellites of this mission.

Although there may be limited possible use of a given ground station by more than one mission, every attempt will be made to minimize the cost of operating the stations. In some cases, it may be possible to share a station location with a non-LWS mission without compromising requirements. In all cases, mission planning will be aimed at minimizing the number of operators and the number of shifts required for efficient operations. The ultimate goal will be to have all the stations completely automated with only periodic maintenance required.

Mission Operations Centers

The Mission Operations Centers (MOCs) are responsible for receiving all science and satellite data from the ground station. The MOC will provide the facilities for the Flight Operations Team, which has responsibility for the health and safety of the satellite and for verifying and validating all satellite and instrument commands prior to uplinking. A detailed breakdown of MOC functions is shown on the following page.

As stated previously, the capabilities of work stations and file servers have increased to the point where they can be used to operate satellite missions and then salvaged or discarded after the missions are complete. Since not all the LWS missions will start operations at the same time, and because it may not be desirable to have all the MOCs at the same location, the capabilities of these MOCs will be sized to effectively and efficiently handle mission requirements.

Maximum use will also be made of commercial off-the-shelf (COTS) software for the MOCs. This offers the advantage of having designed and tested software that requires only customizing to meet the requirements of the specific mission. It also means that the capabilities of the software will be adequately documented and debugged as part of the licensing agreement for its use.

The telemetry formats for all LWS missions will follow the Consultative Committee on Space Data Systems (CCSDS) standards. CCSDS standards will optimize the telemetry rate from the instruments and the satellite housekeeping data. This will also permit the use of COTS telemetry handlers and facilitate the processing and transmission of the telemetry by ground systems.

Mission Operations Center Functions

Mission Operations Center

Real-Time Operations

- Command
  - Selection
  - Validation
  - Transmission
  - Verification
- System Control
  - Network
  - Real-Time Data System
  - Station Control
  - Constellation Control
- Health & Safety Monitoring
  - S/C Configuration
  - Limit Checks
  - S/S Perform Assessment
- R/T Data Accounting
- Contingency Response
- Science Data to SOC

Scheduling

- Network
- Internal Resources
- Pass Plan Generation
- OBC Management

Flight Dynamics Support

- Orbit Determination
- Attitude Verification
- Att. & Orbit Analysis
- Sensor Calibration

Offline Analysis

- S/S Performance Mgmt
- Anomaly Investigating
- Data Recovery
- Anomaly Reporting
- Perf. Assmt. & Trending

Mission Planning

- Science Planning
- S/C Ops. Plng.
- Load Planning
- Load Generation

Continuing Engineering

- Database Mgmt.
- Procedure Maint.
- Display Maint.
- Config. Mgmt.
- Modification Test.
  - Network
  - Inhouse Sys.
  - Spacecraft
- Contingency Plng.
- Archiving
- Status Reporting

Science Operations Centers

Where it can be effectively and efficiently done, the Science Operations Centers (SOCs) will be co-located with the MOCs. This will reduce data transmission costs and permit the personal interaction of the Science Operations Team with the Flight Operations Team.

The SOCs are assumed to be the responsibility of the science teams who will have responsibility for:

- Providing the facilities and the necessary infrastructure for the SOCs
- Design and development of all science data processing operations within the SOCs
- Distribution of science data to other facilities from the SOCs
- Data accountability and the ultimate storage of all science data
- Establishing science operations priorities
- Health and safety of the science instruments